SURVEY PAPER ON THE APPLICATION OF TECHNOLOGY
TO THE FLIGHT MECHANICS OF AIRCRAFT DEVELOPMENT

By

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With additional contributions

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SUMMARY

This paper presents a general outline of the areas of technical interest to the AGARD Flight Mechanics Panel and the relationship of those technological areas to the overall problems of aircraft development.

Specific examples are presented of the technologies applicable to aircraft in conventional modes of flight, as well as VTOL modes.

The relationship of technologies of vehicles are illustrated with identification of critical problem areas and technological gaps, and by examples of the impact of certain known characteristics on the overall vehicle configuration. Emphasis is placed on the relationship of propulsion systems integration into the total vehicle development.

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1. INTRODUCTION

As the words, "survey paper" implies, only a general outline of the areas of technical interest one might see within the scope of the Flight Mechanics Panel's activities and the relationship of those technological areas to the overall problems of aircraft development can be presented in this paper. The Flight Mechanics Panel is interested in the full scope of the aircraft developer's problems. Examining the many related disciplines as they contribute to the final product, one can certainly anticipate interest in aerodynamic efficiency, total propulsive efficiency, flight characteristics, stability and control, automatic control and guidance. The panel is concerned about analytical techniques used by the developer in achieving his final results as well as the subtleties of the demands on the aircraft of avionics and automatic guidance systems and vice versa. In the same sense, the panel has continued to recognize that the ability to achieve accurate, dependable, repeatable information in flight test is important to us for the purpose of providing the designer with a valued and appropriately adequate guage of his analytical processes. Therefore, we are interested in exploring all the problems which are important to the developer as he attempts to solve the requirements of the user.

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The Flight Mechanics Panel is not interested in a detailed exploration of the operator's problems, for we believe this is the responsibility of the military or governmental departments of the individual member nations--not the responsibility of an advisory group to the NATO organization. However, it is important to understand the implications of the operator's problems in assessing the important aspects of the developer's problems. For that reason, a portion of this survey paper will be addressed to appraising some of the problems that the operator sees and how those problems can influence the application of technology. To illustrate the magnitude of the operator's concern and problems, Figure 1 is a representation of the exploratory development interests of the U.S. Navy. The small sector at seven o'clock is that portion of concern to aeronautical engineers. This figure is not meant to illustrate priority or importance but only the total number of technical items that contribute to the basic functions of a warfare system.

These operational problems also relate to the identification of critical technical areas and the impact of changing characteristics on the vehicle development. One additional point should be emphasized: NATO is a military organization and as such we are primarily interested in developments that will be of importance to the military structure. However, in today's growing affluent society throughout the world, it is more and more clear that economic and logistic development is equally as important as specific weaponry in the total context of military survivability. In short, a nation whose economic growth will not support the military structure can not very well defend itself. At the same time, economic stimulation can share the burden of technological development by providing incentive for the disciplinary and technology growth which we will be discussing. This particularly bears on the interest by this panel in the supersonic transport technology (both the European and the U.S. program). We further believe that other transport applications are of interest and important to NATO and AGARD in particular. Let us first look at the picture from the user's (or the operator's) side, whether military or civilian, tactical or logistic. The preparation of a requirement for a new aircraft demands many exchanges between the operational user and the technical producer. To establish a requirement requires that groups of people sit down and "think" out the future of an application with full awareness of what is currently available. Answers must be found to such questions as: What capabilities will be needed to overcome what problems? What opportunities are available to be exploited for continually increasing the capability to overcome these problems? How complete should be the solution? To what extent should specialization and "perfection" be pursued versus compromise and adaptability? How many ways does the operator really need to use the final product and how many different operational environments does this present? If this collection of specific requirements is well thought through and well conceived the result is of utmost utility to the R&D community. Those responsible for initiation of exploratory development can identify weak areas in the technology where increases in the "state-of-the-art" will be needed. The technical community will know better how to trade-off the alternatives of potential systems to give the user the capabilities that technology suggests are possible.

The need for a well thought out operational requirement to support the use of available technology cannot be better illustrated than by review of the V/STOL military or civil application. The helicopter is not considered a high performance machine, yet it is today the only approved operational VTOL machine, in spite of the fact that visionaries in the field have had prototype, high performance, VTOL machines in test for several years. The basic cause of this lack of application of an existing technology appears very clearly to be that it has not been possible to establish a specific operational requirement for aircraft with this capability that would take full advantage of the achievements in propulsion, aerodynamics, structures, weaponry, guidance, and at the same time provide an effectiveness commensurate with its cost.

V/STOL developmental activity has made one outstanding accomplishment--it has stimulated a tremendous surge in technology and advancement in the state-of-the-art. One must recognize however that the advancements in propulsion, aerodynamics and other technical areas apply to the conventionally operated machines as well as to the V/STOL. The user, of course, recognizes the severity of the economic load in today's world, be it military or civilian, and equal effectiveness or marginal increase in value is not a way to capture his attention.

He must have greater gains, he must have greater achievements at a reasonable or less cost. This should not and does not in my opinion minimize our interest in V/STOL activities. In fact, one might say it should maximize our interest in V/STOL technology but we must pursue it in the light of the total system application.

To avoid being misunderstood, let us consider for a moment, the overworked word, "System". To the aerodynamicist or aeronautical engineer, the complete system covers aerodynamic efficiency, performance, handling qualities, etc., and the description of the system can be confined to airfoil sections, aspect ratio, geometry, and other mechanical considerations. The aircraft development project engineer sees the system in terms of not only aerodynamics or aeronautics but also aircraft structures, propulsion, avionics, payload, etc., as Figure 2 illustrates in the delivery function of an air-weapons system. As he sees it, the system is considerably more complex. Now if we go to the military evaluator, his system is only complete if we add to those previously identified, the operational tactics, the environment, the operating characteristics, the airfields or carriers or traffic control systems, etc., and the maintenance of not only the airborne equipment but the ground support equipment necessary to it. Figure 2 indicates these additional considerations required in an air weapon system. Finally, to the operating commander or manager, his view of the system is the summation of all of the above, for each type of equipment he operates, and how they complement one another, to give him a complete capability to provide the solution to his function or to win a war. The point basically is, then, that the meaning of the word "system" is relative to the position or to the viewpoint that one has of the total job and it is time for us to recognize and discuss the interface and the integration of the many components, technologies, and equipments that make up the totality of the aerospace system problem. The Flight Mechanics Panel has recognized this concern--it has attempted in the past two or three years to address a wide area of interest in the technical disciplines but in doing so, to develop understanding of the relationship between them. We cannot claim to be completely successful but we have in the last year and a half had specific sessions on V/STOL handling characteristics; on V/STOL testing techniques and flight simulation; on stability and control characteristics of conventional and V/STOL machines;

and on problems of flight instrumentation. The objective of our meetings is to be of benefit to the specialist in the areas of interest in these disciplines and also to identify the relationship of the particular discipline to the total system integration so that members and observers whether specialists, developers, or users will have a better awareness of values, of the necessity for the pursuit of improvement in their particular areas. Many of us have had the responsibility of operating research or experimental laboratories and to also take on the responsibility of justifying the need for operating dollars to continue experiments in these laboratories; I am sure that the bookkeepers, accountants, and economists of all countries require some reasonable explanation of what can be expected of value or benefit out of the work proposed or accomplished. The Flight Mechanics Panel wishes to be productive and useful in achieving solutions of these problems.

2. DISCUSSION

The papers presented at the 31st Flight Mechanics Panel Meeting are concerned with various aspects of the integration of the propulsion system with the airframe. These papers are intended to call attention to technical problems of particular interest to the Flight Mechanics Panel. The 31st Meeting program was separated into four sessions covering distinct areas of interest, the first two having to do mainly with development activities in conventional flight modes, the other two having to do specifically with VTOL flight problems. Ten papers in all were involved and are referred to throughout this paper as references 1-10.

The objective of the next few illustrations is to bring an overview of the more detailed discussions covered in these papers. We will also try to relate the particular subject area being addressed at this meeting to other areas of interest of the Flight Mechanics Panel. Three papers (References 1-3), which comprised the first session of the meeting, deal with specific technical problems of the influence of a propulsion system in an airplane principally in conventional flight modes. The first of these is a discussion of one of the perennial problems of subsonic, or supersonic operations for that matter, that is, thrust measurement. How does one really know what the thrust-drag relationship really is? The second paper deals with the influence of jet exhaust on the aircraft characteristics in transition as well as in high-speed regimes. The third deals with specific aspects of auto throttle control. The second session, still concerned with conventional flight areas consisted of three papers dealing with integration problems. The first of these (reference 4) is a paper on the engine-airframe integration of a subsonic application. References 5 and 6 deal with the engine-airframe integration on a supersonic application. Of these, the first paper is concerned with U.S. military activity and the second with the Concorde supersonic transport.

It is well recognized that one of the major problems of conventional supersonic aircraft is the matching of a propulsion unit and an airframe to produce an effective aircraft system. This subject has been discussed before. Figure 3 (taken from reference 11) illustrates the influence of engine location on the inlet pressure recovery as a function of angle of attack for a high-performance, mixed-compression, axi-symmetric inlet, located in several locations on a representative airplane configuration. The basic characteristics of the isolated inlet operating in the free stream are shown by the dotted line. The predominantly favorable influence of the change in flow angularity effected by the fuselage or wing is indicated by the other curves. The optimum inlet location from the standpoint of pressure recovery--for this configuration--is beneath the fuselage centerline. Performance of the inlet located above the fuselage centerline is good up to cruise angles of attack but deteriorates rapidly at high angles mainly because of the rapid build up of local Mach numbers in the region of the inlet.

The aerodynamics specialist may immediately recommend to put the engine under the fuselage. But the designer (or system integrator) expects the propulsion-system inlet to do more than just provide a high pressure recovery with minimum drag; it, among other things, must be compatible with the engine which it serves.

Improper integration into an airplane system is illustrated in figure 4 where we can see what can happen to one of the engine operating margins. The upper solid line is the normal surge line of an engine, providing an adequate stall margin above the engine operating line. Steady-state or dynamic flow distortions entering the inlet or produced by an inlet can substantially reduce the level of the surge line. In this illustration the reduction or elimination of the margin for transient operation is shown. Such transients occur during engine acceleration or during airplane maneuvering and aggravate inlet flow distortions into the compressor. Furthermore, the designer may have problems, such as the integration of weapons, or a particular functional loading, or other internal systems which conflict with the location of the engine as optimized by the aerodynamicist.

Reference 2 is of particular interest with regard to functional problems and their impact on integration. This paper deals with a particular conventional flight problem that was of interest during the development of a V/STOL aircraft. It should be emphasized that these problems of integration are not confined to the sophisticated supersonic aircraft or V/STOL aircraft development programs. Operating aspects can generate problems whenever a hostile operating environment is a serious consideration. Reference 4 deals with integration problems when foreign object damage of the engines is a paramount factor.

Considerations of the integration of the propulsion system and airframe for V/STOL aircraft are, of course, complex and of prime importance. The entire field could not, by any means, be covered in one conference, or in one day, or specifically in the four papers (references 7-10) making up the third and fourth sessions of the Panel meeting; it was intended that meaningful papers on the subject would be provided that, when put together with other contributions (both from activities of other panels as well as contributions from general publications and future conferences) would provide some contribution to the general understanding.

Figure 5, borrowed from Mr. Hammond's paper, (Reference 7) identifies the general concerns and causes of the problems generated by hot gas ingestion, which is also considered in reference 9. Obviously when a 15% loss in engine thrust can be caused by a 40°F temperature rise in the inlet air, it's a serious problem. When these effects are further compounded by uneven temperature distribution at the face of the inlet, compressor stalls can easily be produced resulting in even greater loss of power and control as well.

This is not a completely hopeless situation, however, and Figure 6 shows an example of how the subtleties of configuration changes can be beneficially used. We have provided a single illustration out of an extensive series of tests which have been previously reported (Reference 12). This figure presents the results of the investigation of changes in wing and cruise-inlet location on a configuration with four lift engines mounted in tandem, with inlets on the top center line of the fuselage. The upper portion of the figure shows the original configuration with an under-the-wing inlet for the cruise engine and circulation patterns which result in lift-engine inlet temperatures as high as 200 degrees F during the course of an eight second run. The lower portion of the figure shows results obtained with a modified configuration having a different location of the wing and the cruise engine inlet. In this case, the wing deflects the hot gas back into the vicinity of the exhaust nozzles avoiding the ingestion into the inlet and therefore, eliminating the inlet temperature rise.

We call attention quickly to the point that not only is the propulsion system affected by problems such as hot gas reingestion but so also is the structure, the lift of the vehicle, and the ability to operate in the VTOL mode. Calling attention to Figure 6 again, it would be obvious that the structure on the lower portion of the fuselage might be considerably penalized by the entrapment of the hot gases under the wing and fuselage. At the same time, the high energy air undoubtedly produces a relatively high lift effect by being trapped. That lift effect, however, decreases as the vehicle leaves the presence of the ground thereby contributing to control and transition problems. This general subject has been discussed in many reports including Reference 13 in which it was observed that favorable interference effects can be obtained and in many cases can be utilized; however, there is a very complex trade-off between control capability, structures, and the penalty of high temperatures on the alighting gear, armament, or the payload. These high temperatures and high pressures also constrain the aircraft to particular operating environments or geography.

Provision of a satisfactory flight-control system with minimum penalty to the overall performance remains a primary aircraft design problem, especially for V/STOL aircraft in the hover and low-speed flight regimes. Since dynamic pressures are too low during these phases of flight to provide effective use of aerodynamic-control surfaces, control energy must be derived from other sources, usually the propulsion system of the aircraft. Failure to provide powerful enough control is obviously a serious safety factor.

In many respects, even more important than the basic requirements of safety, are the requirements for confidence on the part of the pilot. If the pilot is limited in his ability to control attitude during the necessary slow down and landing maneuvers, he will increase the time required for the final approach to a vertical landing. This will increase the amount of fuel consumed--thereby requiring more fuel with a corresponding decrease in pay-load, and will result in poor vehicle utilization.

Because of this sensitivity of the control requirements and the impact on the total performance of the vehicle in a VTOL design, the designer is extremely interested in identifying minimum acceptable levels of control under varying conditions. Much serious effort by many people is going into this area.

Requirements for control about the roll axis of V/STOL aircraft are usually considered by the pilot to be the most critical. The roll control must be powerful enough to serve a number of functions; that is, trimming, controlling in the presence of external disturbances, and for maneuvering. Roll control power needed for disturbance correction and maneuvering is not only affected by the configuration, but by the aircraft size as indicated in Figure 7. It has been concluded in a previous study (Reference 12) that the magnitude of an upset, in rad/sec^2, is inversely proportional to the square root of the weight. Although the upsetting moments increase with increase in aircraft size because of the area exposed, the moment of inertia increases at a greater rate, resulting in a decrease in the upsetting accelerations. The control power required for maneuvering is also shown in Figure 7.

It appears from this figure that the maneuvering acceleration requirement will be essentially similar for similar types of aircraft even though the weight may vary considerably. It also appears logical that large aircraft, such as transports, may not require large and rapid maneuvers and therefore the maneuvering acceleration control power would be somewhat reduced. However, this is not to say that the power required to produce adequate control will not increase with size. In this analysis, the moments of inertia have increased with weight, and therefore the system power required to produce the same magnitude of acceleration will go up at the same rate as the moments of inertia. This figure suggests that a total control acceleration requirement can be specified for V/STOL aircraft, by classes, as is done for conventional aircraft. Other aspects of V/STOL control are discussed in references 8 and 10.

An equally important aspect of VTOL low-speed flight is the inherently low level of aerodynamic stability. Almost any system which provides control for the pilot under these conditions can also be used to augment the stability of the aircraft. There has been considerable controversy in recent years regarding the way in which this should be done or, in fact, whether or not it should be done. Cost, complexity, reliability, and maintainability considerations of stability augmentation systems must be weighed against the improvements in handling qualities achieved and the potential reductions in total control requirements. Although it is generally considered desirable to design an aircraft so that it can be flown satisfactorily without stability augmentation, such augmentation will be very desirable and may be necessary for carrying out certain specialized missions.

An example of the effective use of stability augmentation in low speed operation is illustrated by recent studies of the NC-130B STOL aircraft at the NASA Ames Research Center (Figure 8). While we have been generally addressing the subject of V/STOL aircraft, this is obviously a STOL aircraft example. The primary reason for bringing it in at this point is to illustrate another facet of the Flight Mechanics Panel's interest, i.e., identification of techniques for developing confidence in our analyses. Ground-simulator and flight studies of the lateral-directional characteristics of this airplane showed that the problem of controlling sideslip at the low speeds used in the landing approach was due primarily to low directional stability and damping. (Figure 9). Turn coordination of the aircraft was therefore augmented with a system that drove the rudder in proportion to roll rate and aileron deflection. The system did not eliminate all sideslip, but the peak sideslip to peak bank angle ratio was reduced to less than 0.3 in a rudder-pedal-fixed turn entry. In addition, directional damping was augmented with a system that drove the rudder in proportion to the rate change of sideslip relative to the airplane flight path. The systems utilized enabled the airplane to be maneuvered to a bank angle of about 15°--with the sideslip automatically restricted to 5°--at a landing approach speed of 70 knots.

It is certainly clear now that our discussion has made a gradual transition in subject matter from aircraft and propulsion integration to a broader area of interest in the activities of the Flight Mechanics Panel. It is our intent here to give a few illustrations of other subject matters which have been and will continue to be of interest to the Panel and to its activities in the total integration sense.

In company with the increased understanding of stability and control response requirements, the use of advanced instrument displays is expected eventually to alleviate greatly the landing problems of aircraft operating under poor weather conditions. (Figure 10). Quantitative definition of the information listed here, its importance to the pilot, and the best means of displaying it to him are important subjects for continued study. Figure 11 illustrates three VTOL aircraft landing displays receiving initial study by the NASA--a conventional display, a moving-map, and a contact-analog concept. Present NASA flight studies and similar studies by the U.S. Air Force utilize a high performance helicopter for the display carrier. The most promising concepts will be checked out later with other V/STOL aircraft types. It can be expected that this subject will be the theme of some future meetings of AGARD panels.

It is not expected however that the instrumentation and pilot displays for any aircraft, whether conventional or V/STOL will be much different in the near future from those in use today. If it is assumed this conventional type of equipment is used, the operational procedures for instrument approach by V/STOL aircraft under low-ceiling or low-visibility conditions can be predicted with some confidence. On the basis of present piloting experience, V/STOL instrument approach procedures will be very little better than the procedures for conventional airplanes and helicopters on instrument approaches. Experience with present V/STOL aircraft has shown a high pilot workload imposed by the precision flight required during instrument approaches. The conclusion is then reached that final approaches will probably not be made along curved flight paths nor will any large changes in airspeed or aircraft configuration be made before breakout below the ceiling.

The instrument approach procedure to a V/STOL landing site under very low ceiling or low visibility conditions is therefore expected to be made up of a series of straight segments with only a minimum number of tasks per segment. Figure 12 compares typical operation of a jet VTOL aircraft in the landing approach under visual flight conditions (on the left) and under instrument-flight conditions (on the right). In the visual approach, the pilot can carry out the transition and guidance tasks at the same time, requiring approximately $1\frac{1}{2}$ minutes. The V/STOL approach under instrument conditions is predicted to take considerably longer--about five minutes--during which the various guidance and transition tasks are carried out in sequence and separately because of the increased pilot workload under such conditions. At the speeds flown in the approach pattern, engine thrust will support about 90% of the weight of the aircraft. The additional fuel used under instrument conditions, compared to that required for a visual landing, will, therefore, materially detract from the effectiveness or utility of a V/STOL design in terms of vehicle range and payload.

It is strongly believed that future pilot displays will permit instrument approaches under poor visibility conditions to be carried out almost as easily as visual ones. Until the availability of such displays, high-performance V/STOL applications do not appear imminent. This is not to say that better pilot displays are the only required solution. Flight-test experience with a number of V/STOL aircraft has also made it clear that the safety and rapidity of performing the conversion maneuver are strongly dependent on the simplicity of pilot controls and the flexibility permitted in the operation of the conversion elements. Generally, aircraft types in which only one conversion control has been necessary (in addition to the basic aircraft systems) have proved reasonably straightforward and simple to operate. This has been particularly true when the conversion control can be used independently of other configuration changes, (such as trim systems, or engine power) and when the conversion elements are continuously variable throughout their full range, so that large and sudden changes in aircraft attitude are not required. With these conditions, it follows that such aircraft can be flown at any desired speed by adjusting the conversion elements for proper balance of lift and drag forces. In contrast, the use of more than one additional control, or the necessity for programming several operations, markedly increases the training time and promotes the possibility of pilot errors. The rate of conversion must then necessarily be slowed, obviously resulting in poor utilization, regardless of how good the presentation is, and in fact, the same conclusion can probably be drawn about visual flight operations.

This paper has not and will not discuss economic aspects of V/STOL operation but I do want to call attention to Reference 14 which deals with economic problems and emphasizes the necessity of the effective economically sound V/STOL transport being capable of omni-directional approach and takeoff from relatively small fields that can be dispersed broadly through the community.

The problem of reducing aircraft noise during takeoff and landing for future designs is of utmost concern for both V/STOL and conventional aircraft, particularly in civil use. One approach is to get the aircraft to and from altitude in a shorter distance by using steeper take-off and landing profiles. For the conventional airplane, a 3° approach and a 6° climbout are considered normal. (Figure 13) Intuitively, V/STOL aircraft, with their slower approach speeds and greater power available for climbout, should be able to operate on much steeper flight paths. However, the assessment of the pilot workloads and the display presentation just discussed is a serious limitation that prevents using much steeper climbouts or much steeper approaches than conventional aircraft at the present time. This limitation now appears to be about 6° in the approach and 10° in the climbout, as shown in the figure.

Comparisons of the noise levels of conventional and V/STOL transports using these takeoff profiles are shown in figure 14 (from reference 15). Values are shown of perceived noise level in decibels (PNdB) which would be noted by observers on the ground directly below the airplane--that is, at various points along the ground track. These PNdB values are plotted as a function of distance from the start of the takeoff roll. The horizontal dashed line at 112 PNdB represents what has been judged a tolerable noise level in some communities for current daylight and early evening commercial operations. However, it can be anticipated, judging from the amount of public complaint of aircraft noise, that future designs (especially designs that are anticipated to be operating near residential areas) must have considerably lower levels of noise. The solid lines represent the calculated noise of 40-passenger turboprop and turbofan V/STOL transports from lift-off and through the climbout to an altitude of about 2000 feet using the 10° climbout profile. In order to relate this to the conventional commercial transport noise with which most people are familiar today, the shaded bands have been added to represent measured PNdB levels for large conventional turbojet, turbofan, and turboprop transports.

On the basis of this figure, it would appear that, in operations from a conventional commercial airport, V/STOL transports would produce less community noise problems than present-day transports because of the difference in landing and takeoff profiles but, hardly enough reduction to permit them to operate from small close-in airports or heliports which are likely to be surrounded by noise-sensitive areas of the community. This is especially true because the noise level during vertical take-off and landing operations on the designs considered will be higher on the airport itself than present levels.

Some consideration has also been given to utilizing steeper approaches to reduce the ground noise of conventional transport aircraft. As indicated in figure 15, flight tests have shown reductions in maximum noise intensity of about eight decibels, for conventional designs, when approach angles of 6° were used instead of the normal ILS glide slope of 3°.

Obviously this technique requires certain trade-offs; first, a technical trade-off increasing the landing-gear design requirements to accept a higher descent velocity, and secondly, the implication on passenger acceptance and safety. The critical aspect of the landing maneuver is obviously the rotation for flare near the ground. A concept of improving this aspect, by direct-lift control, is illustrated next.

The upper portion of Figure 16 shows the practical case of an error in aircraft position on the approach glide path. In order to re-establish the path, the aircraft must first be rotated as shown in the middle figure; the time lag involved due to the aircraft's inertia in pitch is too great for accurate control during steep approaches. At the bottom, a flight path correction is illustrated in which the aircraft utilizes direct-lift control to provide a rapid translation with no rotation. Some recent flight programs have indicated the feasibility of using quick-acting wing flaps or spoilers to provide this direct-lift control.

In the higher-speed regimes, several problems require continued study. Consider aircraft designs intended to operate for a substantial portion of flight in the supersonic speed regime. We find that most designs are such that extensive continued maneuvering results in reduction of speed from supersonic to transonic. This eventually leads to transonic flow separation and aircraft buffet with attendant structures, vibration, flight control, instrumentation, and functional system problems, as well as unsatisfactory ride characteristics for the pilot or crew or passengers.

A maneuvering envelope defined by stall and buffet boundaries considered representative of current designs is shown in Figure 17 in terms of lift coefficient, C_L, versus Mach number. The stall, transonic-buffeting, and control-limited speed ranges are indicated. For level flight, as indicated by the dashed curve of lift coefficient for 1-"g" flight, up to the solid line, a buffet-free maneuvering region exists. Also shown is another dashed curve for a higher lift coefficient which would represent either a higher "g" condition or a higher altitude operating condition or possibly higher load carrying situation for a given design. This curve is shown to intercept the buffet boundary at about Mach number 0.85. This represents a limitation in the operating characteristic of the design and one that should be cured. Use of such design features as lower wing loading, improved leading and trailing edge devices, and thrust vectoring may provide means of alleviating this limitation.

The transonic buffet boundary does not represent a maximum lift as does the stall-limited boundary at lower speeds. Thus, sustained flight could be achieved above this buffet boundary, if the flow separation which causes the buffet can be constrained. It is true that for a sudden maneuver a somewhat higher C_L can be obtained before flow separation and buffet occur. The magnitude of the increase depends upon the rate of the maneuver. However, under this condition the intensity of the resulting buffet, when ultimately encountered, will be extreme and it is not a satisfactory operating technique. Preventing the separation or minimizing the separation is the only practical solution.

Finally, although it may be premature for the Flight Mechanics Panel to give much attention to design or operational problems of hypersonic aircraft, there is increasing interest in military applications of aircraft up to Mach 12. In addition, there are strong supporters for the concept that the follow-on to the current development program of a supersonic transport may be a hypersonic transport capable of speeds twice the capability of the present supersonic programs. The NASA research program on the X-15 aircraft and possible follow-on studies of a modified configuration such as that indicated in Figure 18 will continue to provide valuable technical information in this speed regime. This field of hypersonic development is sure to demand even greater complexity and more specific information in the integration of future aircraft designs.

3. CONCLUDING REMARKS

The Flight Mechanics Panel (formerly the Flight Test and Instrumentation Panel) was established in 1952. The 31st technical and business meeting was held on September 13-14, 1967. In this survey paper, an attempt has been made to illustrate our concern with the specific mission of the Panel to promote international cooperation and also to describe the broadening trend toward understanding the applications of science and technology. The Flight Mechanics Panel recognizes the need to be useful to the civil or military operational user as well as to the aircraft designer and the flight test engineer. The 31st meeting was indicative of concern and interest in the integration and the interface between propulsion and the airframe. The potential of such concepts as V/STOL depends to a large degree on the ability to assure high lift for low total weight. The obvious importance of the propulsive unit in the total aircraft "systems" problem, not only because of direct interference effects but also because of the iterative design analyses necessary to reduce subsystem weights, demands the Panel's continued concentration on special technical problems and overall integration problems.

Figure 19 shows some of the many areas of interest to the Panel. We recognize this as a partial list in an expanding aeronautical world, and the activity of the Panel testifies to its desire to provide the man in the cockpit with a more efficient, useful aircraft.

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15. NASA SP-83, "NASA Conference on Aircraft Operating Problems" Langley Research Center, May 10-12, 1965.

SPHERE OF EXPLORATORY DEVELOPMENT

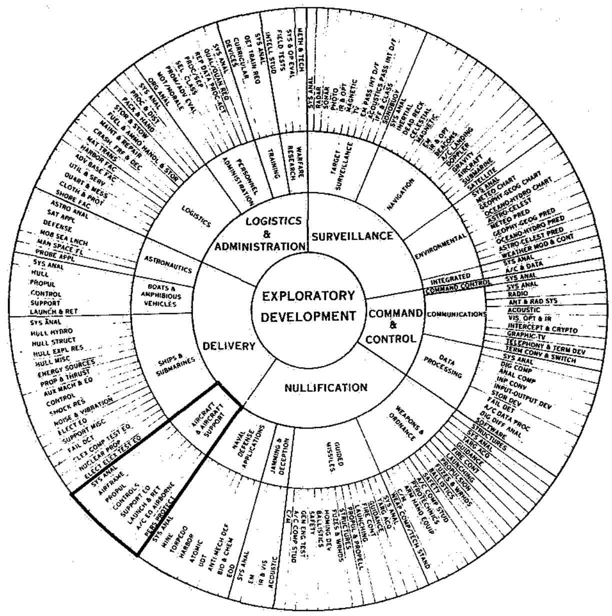


Fig. 1

AIR WEAPON SYSTEMS

SURVEILLANCE	COMMAND CONTROL	NULLIFICATION	DELIVERY	LOGISTIC ADMINISTRATION
RADAR	CREW	BOMBS	AIRFRAME GROUP	TRAINING DEVICES
RADIO	FIRE CONTROL SYSTEMS	GUIDED MISSILES	PROPULSION GROUP	MAINTENANCE FACILITIES
PASSIVE ECM	BOMB DIRECTIONS	TORPEDOES	SURFACE CONTROLS GROUP	FUEL AND OTHER SUPPLY
IFF		ACTIVE ECM	SUPPORT GROUP	STORAGE AREA
ACOUSTIC (SONAR)		ROCKETS	CATAPULTS *	GROUND HANDLING EQUIPMENT
M. A. D.		DEPTH CHARGES	ARRESTING GEAR *	
I. R.		MINES		
OPTICAL AIDS		GUNS		
PHOTOGRAPHIC EQUIPMENT				
NAVIGATIONAL EQUIPMENT				

* THESE ITEMS ARE EXTERNAL TO AIRCRAFT. ALL OTHERS ARE INTERNAL.

Fig. 2

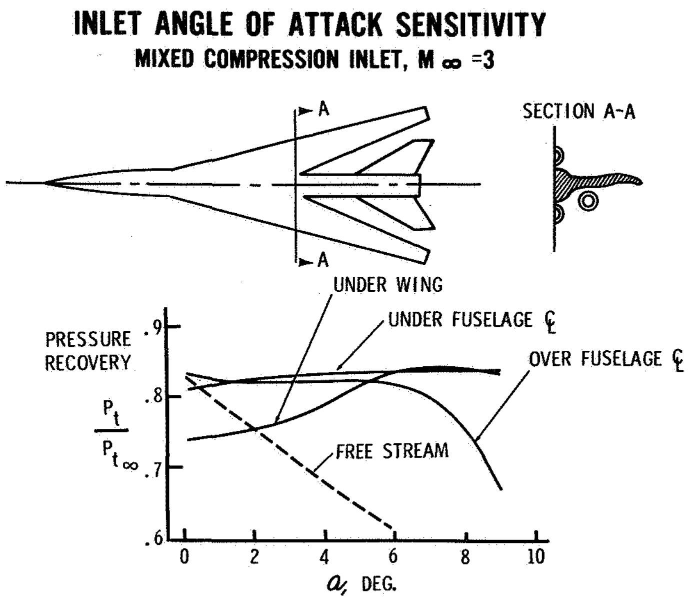

INLET ANGLE OF ATTACK SENSITIVITY
MIXED COMPRESSION INLET, M ∞ =3
A
A
SECTION A-A
UNDER WING
UNDER FUSELAGE ℄
OVER FUSELAGE ℄
FREE STREAM
PRESSURE RECOVERY
$\frac{P_t}{P_{t\infty}}$
.9
.8
.7
.6
0
2
4
6
8
10
α, DEG.

Fig. 3

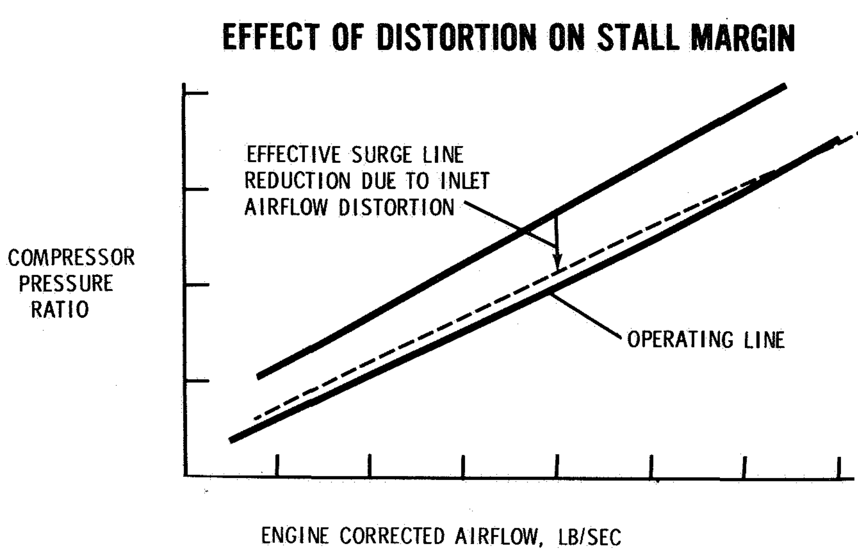
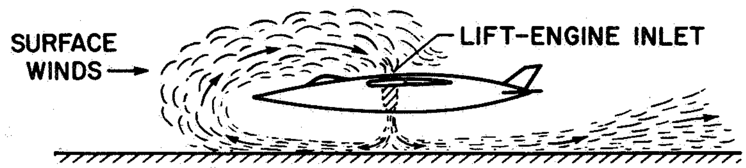

EFFECT OF DISTORTION ON STALL MARGIN
EFFECTIVE SURGE LINE REDUCTION DUE TO INLET AIRFLOW DISTORTION
OPERATING LINE
COMPRESSOR PRESSURE RATIO
ENGINE CORRECTED AIRFLOW, LB/SEC

Fig. 4

HOT-GAS INGESTION



REASONS FOR CONCERN

- THRUST LOSS
  - TEMPERATURE RISE OF 40°F CAUSES 15% LOSS OF THRUST
- COMPRESSOR STALL
  - RAPID TEMPERATURE RISE
  - TEMPERATURE DISTRIBUTION

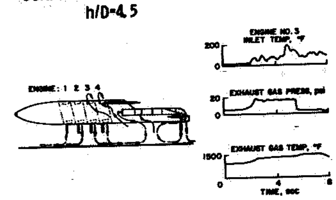
CAUSES

- BUOYANCY OF HOT EXHAUST
- SURFACE WINDS
- CONFIGURATION
  - EXHAUST AND INLET ARRANGEMENT

Fig. 5

EFFECT OF AIRCRAFT CONFIGURATION ON INLET TEMPERATURE RISE

CONFIGURATION HAVING HIGH INGESTION
h/D=4.5



CONFIGURATION HAVING LOW INGESTION
h/D=4.5

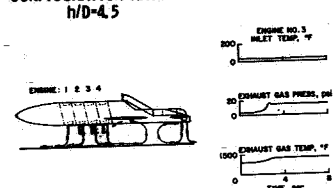


Fig. 6

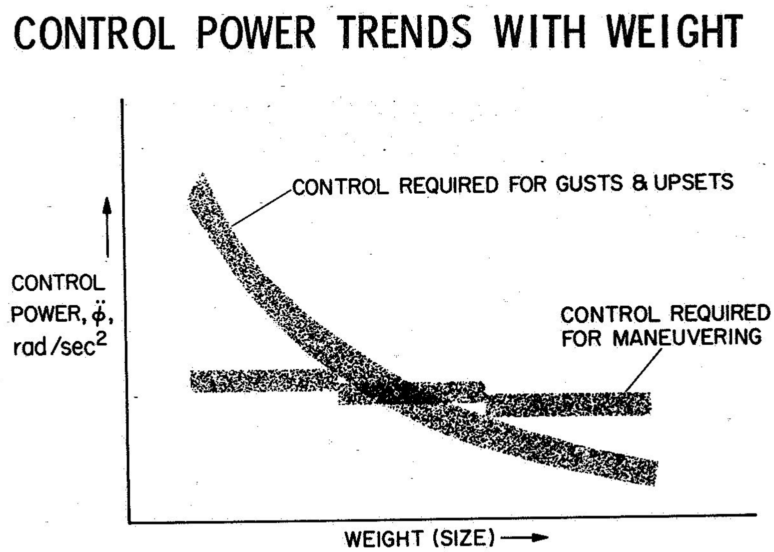

CONTROL POWER TRENDS WITH WEIGHT
CONTROL REQUIRED FOR GUSTS & UPSETS
CONTROL POWER, $\ddot{\phi}$, rad/sec^2
CONTROL REQUIRED FOR MANEUVERING
WEIGHT (SIZE)

Fig. 7


NC-130B STOL AIRCRAFT
80712

Fig. 8

EFFECT OF AUGMENTATION ON PEAK SIDESLIP ANGLE IN TURN ENTRIES

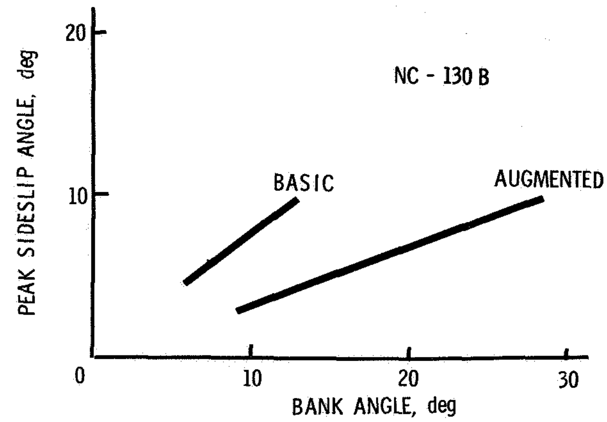


Fig. 9

INFORMATION REQUIREMENTS FOR LANDING APPROACH

ATTITUDE	GUIDANCE	SPEED
ROLL	SLOPE DEVIATION	AIRSPEED
PITCH	COURSE DEVIATION	VERTICAL SPEED
HEADING	RANGE	GROUND SPEED
	HEIGHT	

Fig. 10

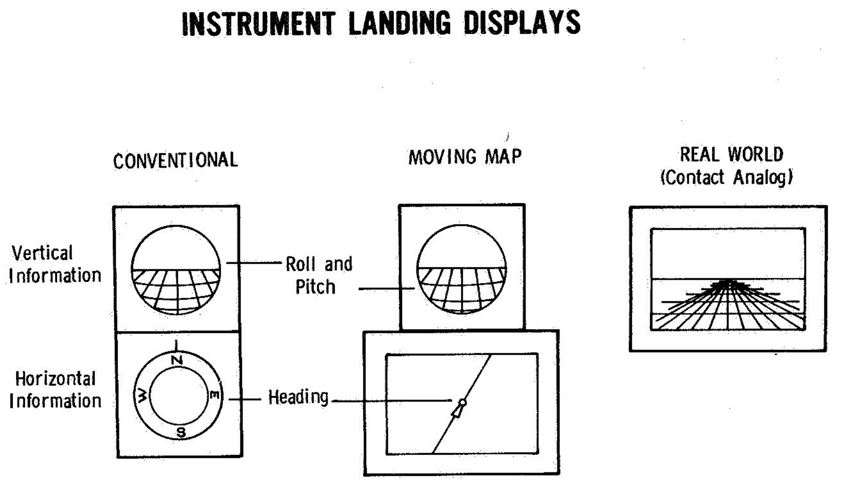

INSTRUMENT LANDING DISPLAYS
CONVENTIONAL
MOVING MAP
REAL WORLD
(Contact Analog)
Vertical
Information
Roll and
Pitch
Horizontal
Information
Heading
N
E
S
W

Fig. 11

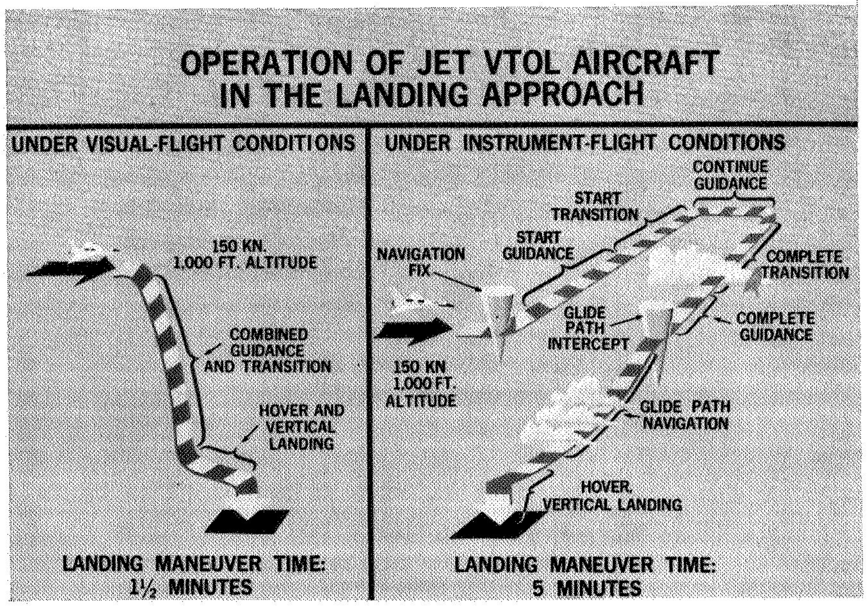

OPERATION OF JET VTOL AIRCRAFT
IN THE LANDING APPROACH
UNDER VISUAL-FLIGHT CONDITIONS
150 KN.
1,000 FT. ALTITUDE
COMBINED
GUIDANCE
AND TRANSITION
HOVER AND
VERTICAL
LANDING
LANDING MANEUVER TIME:
1½ MINUTES
UNDER INSTRUMENT-FLIGHT CONDITIONS
CONTINUE
GUIDANCE
START
TRANSITION
START
GUIDANCE
NAVIGATION
FIX
COMPLETE
TRANSITION
GLIDE
PATH
INTERCEPT
COMPLETE
GUIDANCE
150 KN
1,000 FT.
ALTITUDE
GLIDE PATH
NAVIGATION
HOVER,
VERTICAL LANDING
LANDING MANEUVER TIME:
5 MINUTES

Fig. 12

TAKE-OFF AND LANDING PROFILES

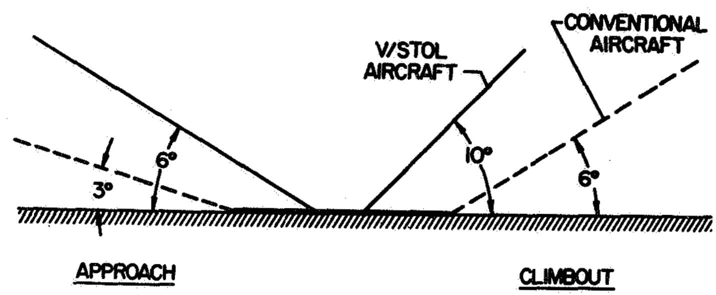


Fig. 13

TAKE-OFF AND CLIMBOUT NOISE

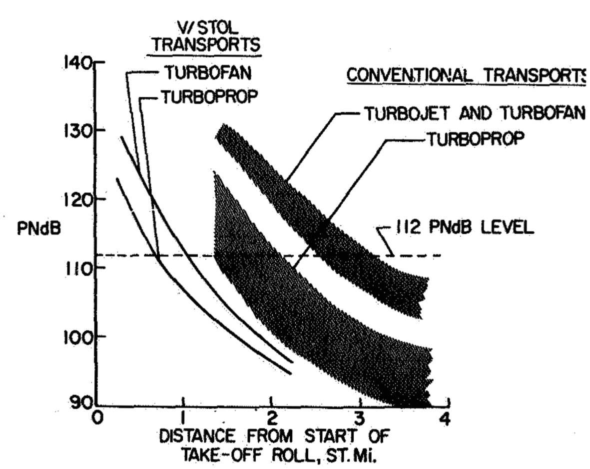


Fig. 14

STEEP APPROACH

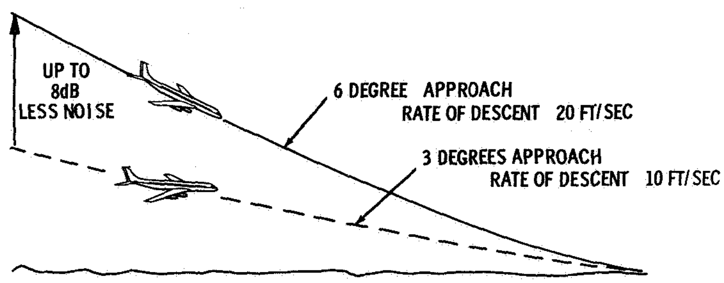


Fig. 15

DIRECT LIFT CONTROL

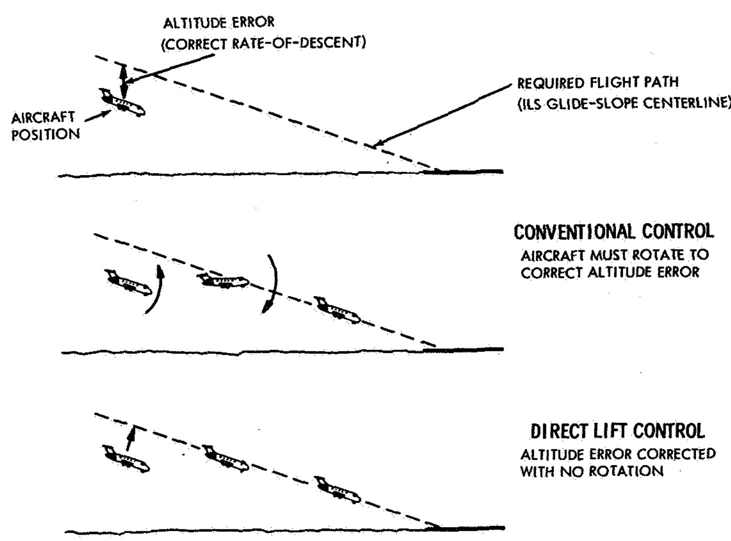


Fig. 16

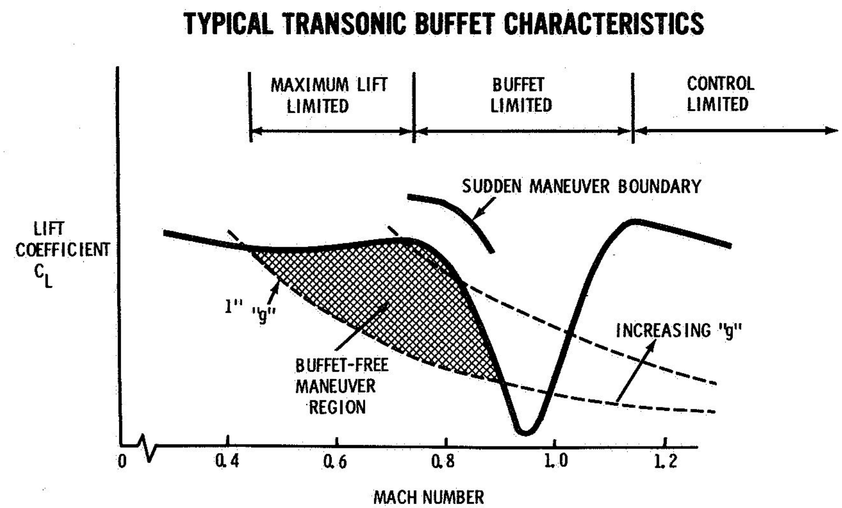

TYPICAL TRANSONIC BUFFET CHARACTERISTICS
MAXIMUM LIFT LIMITED
BUFFET LIMITED
CONTROL LIMITED
SUDDEN MANEUVER BOUNDARY
LIFT COEFFICIENT C_L
1" "g"
BUFFET-FREE MANEUVER REGION
INCREASING "g"
0
0.4
0.6
0.8
1.0
1.2
MACH NUMBER

Fig. 17


REPRESENTATIVE MODIFIED DELTA WING X-15 CONFIGURATION

Fig. 18

AREAS OF INTEREST TO FLIGHT MECHANICS PANEL

V/STOL MODE	CONVENTIONAL FLIGHT
GROUND EFFECT	CONFIGURATION COMPROMISE (VTOL)
RECIRCULATION OF EXHAUST GAS	MULTI-MISSION CAPABILITY
SAND INGESTION	ENGINE-AIRFRAME INTEGRATION
CONTROL, HANDLING QUALITIES	STABILITY AND CONTROL
STABILITY AUGMENTATION	HANDLING QUALITIES
TRANSITION PROCEDURE	PERFORMANCE
DESCENT CAPABILITY	STRUCTURES AND MATERIALS
DISPLAYS	TURBULENCE
PILOT WORKLOAD	AEROELASTICITY EFFECTS
TURBULENCE	STABILITY AUGMENTATION
NOISE	BUFFET
	NOISE
	SONIC BOOM

Fig. 19